

INFLUENCE OF THE ROTATION VELOCITY AND COLLECTOR CONCENTRATION ON THE FLOTATION KINETICS

KARIŐTIRMA HIZI VE TOPLAYICI KONSANTRASYONUNUN FLOTASYON KİNETİĞİNE ETKİSİ

B. Radoev »
L. Alexandrova **

Keywords : Rotation, Impeller Velocity, Attachment Force.

ÖZET

Maksimum flotasyon randımanı (R_{∞}) ve zaman sabitinin (x) karıştırma hızına (N) bağımlılığı, toplayıcı konsantrasyonu, pH ve tane boyutunun fonksiyonu olarak incelenmiştir. Ballotini ve galen deneylerinin sonuçlarından ampirik bir ilişki $x(N)$ çıkarılmıştır. Toplayıcı konsantrasyonu ve pH randımanı arttırmıştır. Tane boyutunun randıman üzerinde fazla bir etkisi görülmemiştir.

ABSTRACT

The dependence of the ultimate recovery R_{∞} and time constant x on the impeller speed N is investigated as a function of the collector concentration, pH and particle size. On the basis of experiments with ballotini and galena particles an empirical relation $x(N)$ is derived. The collector concentration and pH improve the recovery: the higher R_{∞} the faster the process. Particle sizes slightly affect and their influence on R_{∞} is almost negligible.

Dept Phys Chem, University of Sofia, 1126 Sofia, Bulgaria
Central Lab of Mineral Process, BAS, 1126 Sofia, Bulgaria

TÜRKİYE XML MADENCİLİK KONGRESİ, 1993

1. INTRODUCTION

At present flotation is quite good understood as an optimal combination of intensive collisions and successful attachments of mineral particles on bubbles (Leja, 1982; Schulze, 1984; Weiss, 1985). The collision kinetics, strongly depending on the hydrodynamic regime in the cell, is usually controlled by the cell types, by the air flow, the pulp density, but mainly by regulation of the impeller speed. The attachment of the particles on bubbles interface, being a problem of three-phase contact formation, is solved in practice by an appropriate choice of collectors, pH-values, frothers, etc.

In the last 40-50 years considerable effort has been directed to the quantitative estimation of these parameters but regardless of the useful results concerning some details a general consistent theory of flotation is still not formulated. It is well known that in numerous cases flotation kinetics obeys an exponential time-dependence:

$$R(t)/R_m = 1 - \exp(-t/T) \quad (1)$$

usually referred to as "first order chemical reaction model". Here R_∞ is the ultimate recovery, and T is the time constant of the process. According to the kinetic theory, creating the basis of expression (1), T is proportional to the particle collision flux j (per bubble) $T \sim 1/Ej$, with an effective coefficient E equal to the number of attached particles divided by the number of collided particles.

The situation with the ultimate recovery is not so trivial but the application of the Langmuir adsorption model leads to another simple relation (Radoev, 1990): $R = 1 - \frac{T \cdot q_b \cdot C_b}{c_0 + T \cdot q_b \cdot C_b}$, where C_b is the bubble concentration, c_0 - initial particle concentration, and q_b - a factor accounting for the detachment probability of particles from bubbles. Both parameters R_m and T depend on the hydrodynamics and collision

characteristics. The aim of this study is to illustrate, on the basis of concrete experiments» the role of the impeller speed in the recovery as a function of collector concentration, pH-values, and particle size.

2. MATERIALS AND METHODS

The material floated consisted of glass spheres (ballotini) (100-160 μm) and galena particles (20-200 μm). The density of the suspension was $\rho = 40 \text{ g/l}$ i.e. 3-4.10 particles per liter. The collector was dodecylamine hydrochloride at concentrations of 10 and 10 M. The pH - value was set with a universal buffer (0.2 M NaOH, 0.12M CH_3COOH , 0.12M H_3PO_4 , 0.12 M H_3BO_4) and controlled by a glass electrode. The glass particles were cleaned before each experiment with hot bichromate mixture and afterwards repeatedly washed with bidistilled water. Potassium ethylxantogenate aqueous solution of 10 and 10 M was used as collector for galena particles. The pH value of 8,9 was attained by the addition of NaOH and controlled by a pH meter with glass electrode. Pine oil ($2.58 \cdot 10^{-2} \text{g/l}$) was used as frother. The flotation experiments were performed with a mechanical laboratory flotation machine in a Plexiglas cell of 0.5 l capacity (height 11.5 cm, width 6,5 cm and length 7,0 cm) and a rotor-stator system operated at 1600 to 4600 rpm. The air flow rate was 55 l/h. Mean value of bubble radius 500 μm .

The flotation was preceded by agitation (for about 10 min) after which air was fed into the machine, determining the start of the experiment. Duration of the experiment - until the recovery rate (dR/dt) reached zero. The froth product was removed manually 15-20 times per minute with due care not to scoop up any liquid from the pulp.

The detachment force of the adhered particles from the liquid-gas interface was measured by the centrifugal method, after some preliminary procedures as follows.

The glass particles were treated with chromic acid for 15 minutes while continuously stirred; then they were rinsed with distilled water and, while still wet, they were rinsed 3-4 times with the solution studied.

Experience in the field of wettability has shown that the reproducibility of the experimental results requires special care. The glass particles were allowed to absorb for 30 minutes with continuous stirring in a glass beaker in order the adsorption on the solid-liquid interface to reach equilibrium. Portions of the surfactant solution were replaced 3-4 times by fresh solution, taking precautions for the glass particles not to be caught at the liquid - air interface. The glass particles on the bottom were caught at the liquid-air interface by tilting the beaker. The glass particles were left for one hour until the equilibrium contact angle was established and then were transferred with a carefully cleaned spatula onto the surface of the initial solution in the centrifugal tubes.

The glass particles were then subjected to the detaching action of centrifugal forces at different speed for 5 minutes. A "T-24 Yanetzki" centrifuge of maximum speed of 20000 rpm and radius of rotation 3.5 cm was used.

The centrifugal force necessary for detaching a particle from the liquid-gas interface was calculated with the aid of equation.-

$$F_N = 4/3\pi R_p^3 (\rho_p - \rho_L) a$$

where a is the centrifugal acceleration ($a = (nN/30)^2 \cdot R_{rot}$),
 N is the number of revolutions per minute at which detachment takes place, R_{rot} is the radius of rotation, ρ_p and ρ_L are the densities of the particle and liquid, respectively.

3. RESULTS AND DISCUSSION

The analysis of the collision rate in turbulent flow is

based on the gas kinetic model. Here the eddies play the role of the molecules, their velocities are assumed as uncorrelated, and the turbulent temperature $\bar{\theta}_{turb}$ is proportional to the energy dissipation rate e (Chao, 1964 ; Nonaka, 1982, Abrahamson, 1975). From this point of view the collision rate (collision flux) j of mineral particles per bubble is described by three different relations:

$$j \sim c_p d^3 \sqrt{\langle (\text{grad } u)^2 \rangle} \quad (\text{Camp. 1943}) \quad (2^a)$$

$$j \sim c_p d^2 \sqrt{\langle u^2 \rangle} \quad (\text{Abrahamson, 1975}) \quad (2^b)$$

$$j \sim c_p R_b D_t \quad (\text{Nonaka, 1982}) \quad (2^c)$$

Here c_p is the mineral particles concentration; $d (r_b + r_p)$ accounts for the so called effective collision cross section (r_b and r_p - the bubble and particle radii); $\langle u \rangle$ is the

mean square velocity, $\langle (\text{grad } u) \rangle$ is the mean square of the velocity gradients. The velocity gradients in viscous flows are simply related to the dissipation rate e $\langle (\text{grad } u) \rangle \sim e/\nu$, ν - kinematic viscosity; D_t - turbulent diffusion coefficient of the particles. Relation (2^a), known in the literature as "gradient collision mechanism" (Smoluchovski, 1917) is suitable when the collision cross section diameters d are smaller as compared to the length scale of the turbulent eddies X . (Abrahamson 1975). These conditions are satisfied at a relatively low dissipation rate e . Relation (2^b) describes the collision rate for larger particles ($r_p > 100$

μm) and at higher energy dissipations (Abrahamson, 1975). Here $\langle u \rangle = \langle u_b \rangle + \langle u_p \rangle$ is the sum of the mean square velocities of the colliding bubble and particle (sum of the velocities dispersions).

The diffusion model (2^c) is another approximation for the cases of relatively large bubbles and highly concentrated suspensions of small particles. Since the turbulent kinetic energy is supposed to be much larger than the thermal energy

Table 1. Effects of the rotation velocity N on time constant T and ultimate recovery R at two collector concentrations, for ballotini (100-160 μm) and pH = 11.2.

N rpm	10 ⁻²		10 ⁻³	
	Time const. T [min]	Ultimate recovery R _∞	Time const. T [min]	Ultimate recovery R _∞
1600	1.01	0.7500	0.70	0.9000
1700	1.00	0.7200	0.70	0.9030
1800	1.00	0.7300	0.70	0.8945
1900	0.90	0.7810	0.70	0.8900
2000	1.04	0.7340	0.70	0.8800
2150	0.95	0.7500	0.64	0.9075
2250	1.10	0.5730	0.64	0.8965
2300	1.20	0.4965	0.64	0.8970
2900	1.40	0.4095	0.70	0.9040
4600	1.70	0.1180	0.95	0.2980

Table 2. Effects of the rotation velocity N on time constant T and ultimate recovery R at two collector concentrations for ballotini (300-400 μm) and pH = 11.2.

N rpm	10 ⁻²		10 ⁻³	
	Time const. T [min]	Ultimate recovery R _∞	Time const. T [min]	Ultimate recovery R _∞
1600	0.64	0.7020	0.52	0.8650
1700	0.64	0.7028	0.52	0.8600
1900	0.68	0.6900	0.53	0.8500
2150	0.68	0.7110	0.52	0.8650
2300	0.73	0.4500	0.52	0.8700
2900	0.76	0.3500	0.51	0.8820

Table 3. Effects of the rotation velocity N on time constant T and ultimate recovery R for ballotini (100-160 μm) at concentration 10⁻² M and pH = 6.

N rpm	10 ⁻²	
	Time const. T [min]	Ultimate recovery R _∞
1600	0.88	0.6167
1700	0.71	0.6001
1800	0.71	0.6278
1900	0.87	0.6004
2000	0.94	0.5950
2150	0.95	0.5890
2250	1.13	0.4965
2900	1.40	0.3025

Table 4. Effects of the rotation velocity N on time constant T and ultimate recovery R_∞ at two collector concentrations for galena (20-200 μm) and pH = 8,9.

H rpm	10 ⁻²		10 ⁻³	
	Time const. T [min]	Ultimate recovery R _∞	Time const. T [min]	Ultimate recovery R _∞
1600	0.61	0.8342	0.49	0.8968
1800	0.76	0.8011	0.47	0.9121
2000	0.67	0.8200	0.47	0.8975
2150	0.67	0.7430	0.46	0.9239
2250	0.99	0.6807	0.47	0.8750
2300	1.27	0.5641	0.50	0.8050
2900	1.24	0.2543	0.55	0.7975

(kT), the diffusion coefficient D should depend on the dissipation rate ϵ (and on the particle radius r_p) rather than on the temperature T . In homogeneous isotropic turbulent flow the relation $D_1(\epsilon, r_p)$ could be established as (Nonaka, 1982):

$$\text{a) } D_t \sim (\epsilon r_p)^{1/3} \quad \text{at } r_p > \lambda \quad (3^a)$$

$$\text{b) } D_t \sim (\epsilon/\nu)^{1/2} r_p^2 \quad \text{at } r_p < \lambda \quad (3^b)$$

where $\lambda = \nu/u$ is the Kolmogoroff length micro-scale.

As mentioned above (see Introduction), the collision flux j is proportional to the rate constant $T \sim E j$. According to relations (2) j is a power function of N , so it could be expected that $T^{-1} = N^{1+m}$ with $m > 0$. The data in tables (1-4) do not confirm such a behaviour.

On the contrary, at $N > 2000$ rpm the process slows down abruptly and the ultimate recovery drops drastically. The data in all four tables satisfy the empirical relation $\ln(T/N^2) = A + B.N$, the constants A, B being evaluated by linear regression analysis (see table 5).

At the moment the relation $E(N)$ is quite poor understood. Regardless of this fact, the experimental result $E(N)$ could be qualitatively explained by the following considerations: at higher velocities N the turbulent pulses destroying the bubble-particle aggregates get stronger and the probability of three-phase contact building should decrease (compare $T(N = 1700) = 1$ min and $T(N = 2400) = 1.4$ min; $R(N = 1/00) = 0.72$, and $R_{\infty}(N = 2400) = 0.41$, etc., see tables 1-4).

The role of the collector concentration on the recovery kinetics could be treated in the frames of a similar reasoning: the better the hydrophobization the higher the attachment probability, i.e. the better the recovery and faster kinetics: $T(10^{-5}M) \sim 1.2$ min, $T(10^{-4}M) \sim 0.7$ min; $R(10^{-5}M) \sim 0.75 - 0.4$, $R(10^{-4}M) \sim 0.9$, See table 1).

A quantitative measure of the hydrophobization degree is the three-phase contact (adhesion) force (F). Some experimental data of F obtained by the centrifugal method

TPC

(see Materials and Methods) are presented in Table 6. A comparison between macroscopic parameters T , R and the microscopic characteristics F_{TPC} confirms the supposed role of the adhesion forces on the flotation kinetics.

Table 5. Constants A and B in the empirical relation $\ln(T \sim W) = A + B.N$ for different cases, evaluated by linear regression (regression coefficient 0.98).

Balotini		100-160 μm		300-400 μm	
PH	$C_{\text{DDA}} \gg \ll$	A	B	A	B
6.0	10^{-5}	-12.2749	-0.0014		
11.2	10^{-*}	-12.8252	-0.0012	-12.7283	-0.0009
11.2	10^{-4}	-13.0318	-0.0009	-13.0318	-0.0009
Galena		20-200 μm			
PH	$C_{\text{KEtX}} [M]$	A	B		
8.9	10^{-5}	-11.9589	-0.0015		
8.9	10^{-*}	-12.5885	-0.0009		

Table 6. Three - phase contact force (F_{TPC}) measured by the centrifugal method. Number of the particles in the centrifuge tube $n \sim 4$; $F_{\text{TPC}}(1)$ - the force for a single particle.

Balotini			Galena			
PH	$C_{\text{DDA}} [M]$	$F_{\text{TPC}}(1) \times 10^0$ [dyn]	PH	$C_{\text{KEtX}} [M]$	$F_{\text{TPC}}(1) \times 10^0$ [dyn]	$F_{\text{TPC}} [dyn]$
11.2	10^{-5}	1.96	8.9	10^{-8}	3.2	12.83
11.2	10^{-*}	2.01	8.9	10^{-*}	4.08	17.39
6.0	10^{-5}	0.94				

Data for $F(n)$ here demonstrate another very strong effect of the number of attached particles n (per bubble) on their adhesion force $F(n)$. There are many reports in the literature confirming the so called "collective-capillary effect" (Varbanov, 1988, Alexandrova, 1992), but satisfactory explanation of its role on the recovery still lacks.

R E F E R E N C E S

Abrahamson, J., 1975; "Collision Rates of Small Particles in a Vigorously Turbulent Fluid", Chem.Eng.Sci. Volume 30, S. 1371-1379.

Alexandrova, L. and B.Radoev, 1992; "Correlations Between the Recovery, the Degree of Hydrophobization and the Rotation Velocity in a Flotation Cell", In Proceeding of the 4 Int. Min.Process. Symposium, G.Ozbayogly (Ed.), Antalya, Turkey, 20-22 October, Volume 1, S.420-430.

Camp, T.R. and P.C.Stein, 1943; J.Boston Soc.Civil Engrs. Volume 30, S. 219-230.

Chao, B.T., 1964; "Turbulent Transport Behavior of Small Particles in Dilute Suspensions", Österreichisches Ingenieur - Archiv., Volume 18, S. 7-21.

Leja, J., 1982; "Surface Chemistry of Froth Flotation", Plenum Press, New York.

Nonaka, M., T. Imaizumi and T. Imaizumi, 1982; "A Micro - Hydrodynamic Flotation Model and its Application to the Flotation Process", In Proc. of XIV Int. Min.Proc.Congress, October 17-23, 1982, Toronto, Canada, Volume 111-9, S. 1-19.

Radoev, B., L.Alexandrova and S.Tchaljovska, 1990; "On the Kinetics of Froth Flotation", Int.J.Miner.Process., Volume

28, S. 127-138.

Schulze, H.. 1984; Physico-Chemical Elementary Process in Flotation Analysis from Point of View of Colloid Science ", Elsevier, Amsterdam.

Smoluchowski. M. . 1917; Z.Phys.Chem., Volume 92, S. 129-145.

Varbanov, R., S. Tchaljovska and I.Nishkov. 1988; "On an Experimentally Established Collective Effect of Microspheres Floated on the Liquid/Gas Interface", In Proc. Prof, of Fine particles, A Plumpton (Ed) Montreal. Canada, S 151-157.

Weiss, N. , 1985; "Mineral Processing Handbook", S.M.E., AIMMPE, Inc. New York.